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Temperature Measurement of Beryllia Ceramic Surface in the Presence of Reflected Extraneous Radiation Using a Multiwavelength Pyrometer

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May 2001

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Introduction

It is often advantageous to employ pyrometry to measure the temperature of a surface. However, reflected radiation originating from sources surrounding the surface of interest is inevitably also included into the measurement process. Inclusion of this extraneous radiation component will introduce erroneous result. This report discusses the use of a multiwavelength pyrometer in a laboratory experiment to measure the temperature of a beryllia ceramic tube surface heated by a propane torch flame while a copious amount of extraneous radiation produced by a quartz lamp was simultaneously reflected by the beryllia surface into the pyrometer (Fig. 1). The multiwavelength pyrometer successfully determined not only the temperature of the beryllia surface but also that of the quartz lamp filament.

Method and Results

Temperature measurements reported in this report are performed using a multiwavelength pyrometer. The multiwavelength pyrometer is configured to accept signals via a 20-meter long silica optical fiber. It is calibrated by a blackbody furnace set to a known temperature as indicated by type K thermocouples. For this experiment, the multiwavelength pyrometer was configured to work between approximately 0.5 to 2.5 μm. At the shortest end of this spectral region, the calibrating blackbody furnace (whose temperature was at 1293.6 K) radiation has just sufficient intensity for the pyrometer's silicon detector to generate a barely detectable signal. Another detector also employed to cover the other end of this spectral range was a lead sulfide detector. After calibration, the radiation spectrum of the blackbody furnace was recorded using the multiwavelength pyrometer. This spectrum is shown in Fig. 2, where a good fitting Planck curve of that temperature is superimposed.

To introduce extraneous reflection radiation into our experiment, a nominal 100 W quartz lamp in a housing with a focusing lens and fiber output connector was used. The input end of the multiwavelength pyrometer's optical fiber was coupled to this output connector. The quartz lamp power supply was adjusted such that the quartz lamp generated only 60 W of power. A higher power supply setting resulted in the multiwavelength pyrometer detector becoming saturated. The recorded spectrum is shown in Fig. 3. The quartz lamp housing fiber connector fixture was next removed to allow the focusing lens to project a beam of quartz lamp radiation on the surface of the beryllia sample that was being studied. The sample was a beryllia ceramic tube that was used in the construction of the NASA designed gas temperature measurement probe (Ref. 1). The input end of the pyrometer's silica fiber was positioned at an angle to receive quartz lamp radiation being reflected by the beryllia surface into the multiwavelength pyrometer spectrometer. The recorded reflected radiation spectrum is shown in Fig. 4.

Later, this relative arrangement between the quartz lamp, the beryllia ceramic, and the multiwavelength pyrometer's input optical fiber was maintained and undisturbed, but the quartz lamp was not turned on. The beryllia ceramic was raised to an unknown high temperature using a propane torch flame. An emission spectrum of the beryllia ceramic was recorded, and is shown in Fig. 5. Maintaining the propane torch flame at the same intensity, the quartz lamp was turned back on to the same power supply setting as before. A radiation spectrum was again recorded. This spectrum consisted of radiation emitted by the hot beryllia ceramic surface as well as quartz lamp radiation reflected by the beryllia ceramic surface. It is shown in Fig. 6.

Analysis and Discussions

We analyzed the quartz lamp radiation spectrum data in Fig. 3 according to the procedure we have employed (Ref. 1) by transforming Eqn. (1), which is Planck's law of blackbody radiation at temperature T

$$L_\lambda(T) = \varepsilon_\lambda \tau_\lambda \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2/\lambda T) - 1} = \varepsilon_\lambda \tau_\lambda \frac{c_1}{\lambda^5} \exp(-c_2/\lambda T) \frac{1}{1 - \exp(-c_2/\lambda T)} \tag{1}$$

into the form

$$y = \left(\frac{\mathrm{Ln}\left(\frac{c_1}{\lambda^5} \frac{1}{L_\lambda} \right)}{c_2/\lambda} \right) - \frac{\mathrm{Ln}\left(1 - \exp(-\frac{c_2}{\lambda T}) \right)}{c_2/\lambda} = \frac{1}{T} - \frac{\lambda}{c_2} \mathrm{Ln}(\varepsilon_\lambda \tau_\lambda) \tag{2}$$

where $c_1=2\pi hc^2$, $c_2=hc/k$ are the radiation constants, with c being the velocity of light, h Planck's constant, k Boltzmann's constant, L_λ the radiation intensity, ε_λ the emissivity of the radiation source, and τ_λ the transmissivity of the optical medium between the pyrometer and the radiation source at wavelength λ. The quartz lamp spectrum data (Fig. 3) is plotted according to Eq. (2) to produce a straight line in Fig. 7. From its intercept a temperature of 3200 K is obtained. It can be noticed that the data are well fitted by two straight lines having the same intercept, but possessing different slopes. These slopes are related to the combined effects of quartz lamp filament emissivity (ε_λ) and the total transmissivities (τ_λ) of the quartz lamp bulb envelope and the lamp housing's focusing lens whose products in the two spectral regions are almost constant. By similarly transformation and analysis of the spectrum in Fig. 5 according to Eq. (2) to fit a single straight line, from whose intercept the unknown beryllia ceramic temperature was determined to be 1230 K. The result is shown in Fig. 8.

In a general application environment, radiation from sources other than just the surface of interest is detected simultaneously by the pyrometer. Radiation of surfaces whose temperatures we seek to measure using a pyrometer will be inevitably corrupted by non-surface origin extraneous components, such as the spectrum in Fig. 6 reveals. The temperature determined would be incorrect. We will show how we can determine the temperature of surfaces even from corrupted radiation data.

By dividing the reflected intensities at each wavelength of the spectrum in Fig. 4 by the incident intensities of the corresponding wavelength of the spectrum in Fig. 3, a spectral reflectivity σ_λ of the beryllia ceramic surface is obtained (Fig. 9). It is obvious that the spectrum in Fig. 6 does not possess the Planck functional appearance because it contained contributions from both emitted and reflected sources whose temperatures are different. We represent it as S_λ, where

$$S_\lambda = g\,[\varepsilon_\lambda\, L_\lambda(T_s) + \sigma_\lambda\, L_\lambda(T_e)] \tag{3}$$

$$\varepsilon_\lambda = 1 - \sigma_\lambda \tag{4}$$

where T_s is the unknown surface temperature , T_e is the temperature of the extraneous quartz lamp radiation source, and g is a geometric factor related to any change which the pyrometer's optical arrangement (in position and orientation) might have undergone between calibration and when it was finally used in the experiment.

The reflectivity σ_λ , and hence also ε_λ, are experimentally determinable, known quantities. Using different value sets of (T_e,T_s,g), Eq. (3) is calculated. The minimum value of the sum of squares of the differences between the calculated (according to Eq. (3)) and the experimentally measured quantities (the spectrum of Fig. 6) was found to be 0.0506 for the N = 440 wavelength channels. The values of T_e and T_s which produced this minimum were the temperatures we sought. They were 3252 K and 1233.6 K respectively. They were thus the best estimates of the quartz lamp filament and the beryllia ceramic surface temperatures obtainable from the data in Fig. 6. These temperatures were in excellent agreement (respectively within 1.6 % and 0.3 %) with the temperatures determined from the non-contaminated spectra in Figs. 3 and 5. A best estimate of the value of g was also obtained, but its significance and value does not concern us here.

Conclusion

The temperature of a beryllia ceramic surface, subjected to extraneous radiation illumination was measured using the multiwavelength pyrometer by decomposing the measured radiation spectrum into the constituent parts. A one time, pre-experiment measurement of beryllia reflectivity was used. This reflectivity measurement is not necessary for materials whose reflectivity does not vary drastically with wavelength when the use of an adjustable unknown fitting parameter would be sufficient. Ordinary 1- and 2-color pyrometers are unable to measure the correct temperature under the present conditions where the pyrometer signal is corrupted. This method we have described would be very valuable for in situ measurement of turbine blades temperature, when the blades are located close to the vicinity of the combustion chamber where the combustion fireball constantly illuminates the blades.

References

(1) Gustave Fralick and Daniel Ng, Pyrometric Gas and Surface Temperature Measurements, NASA/TM—1999-20959.

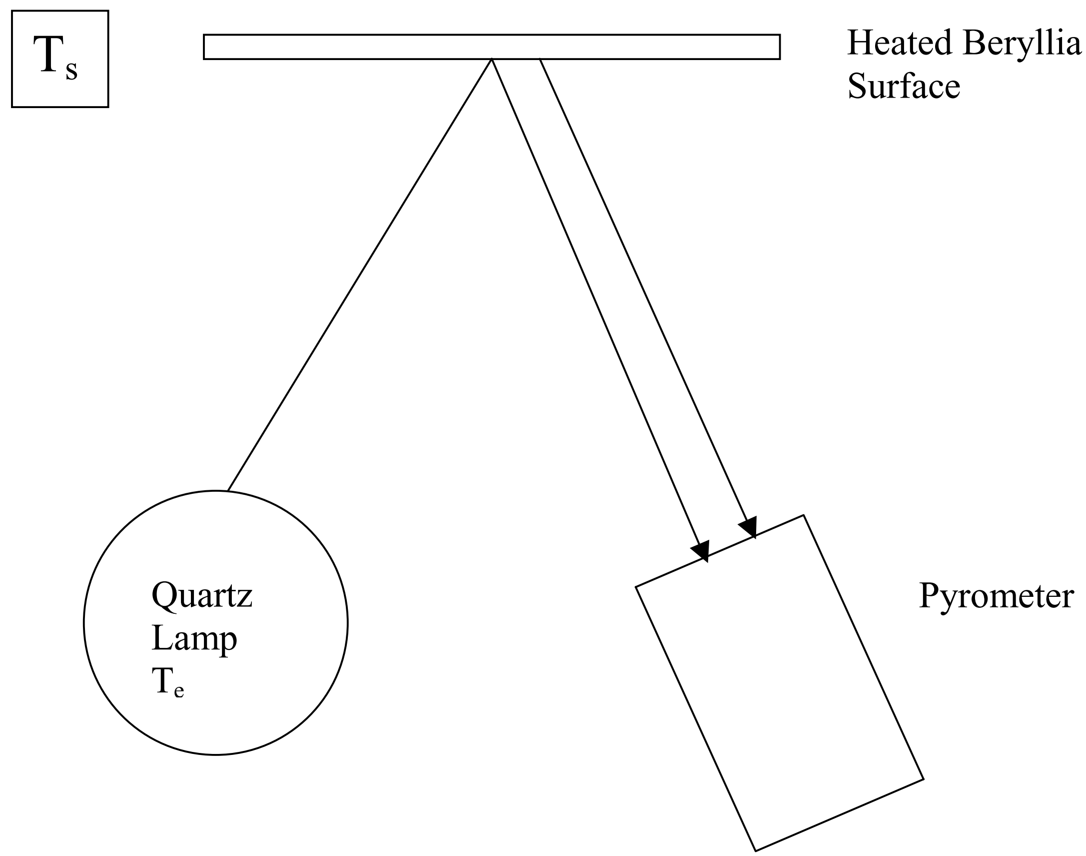

Fig. 1 Schematic of Experiment

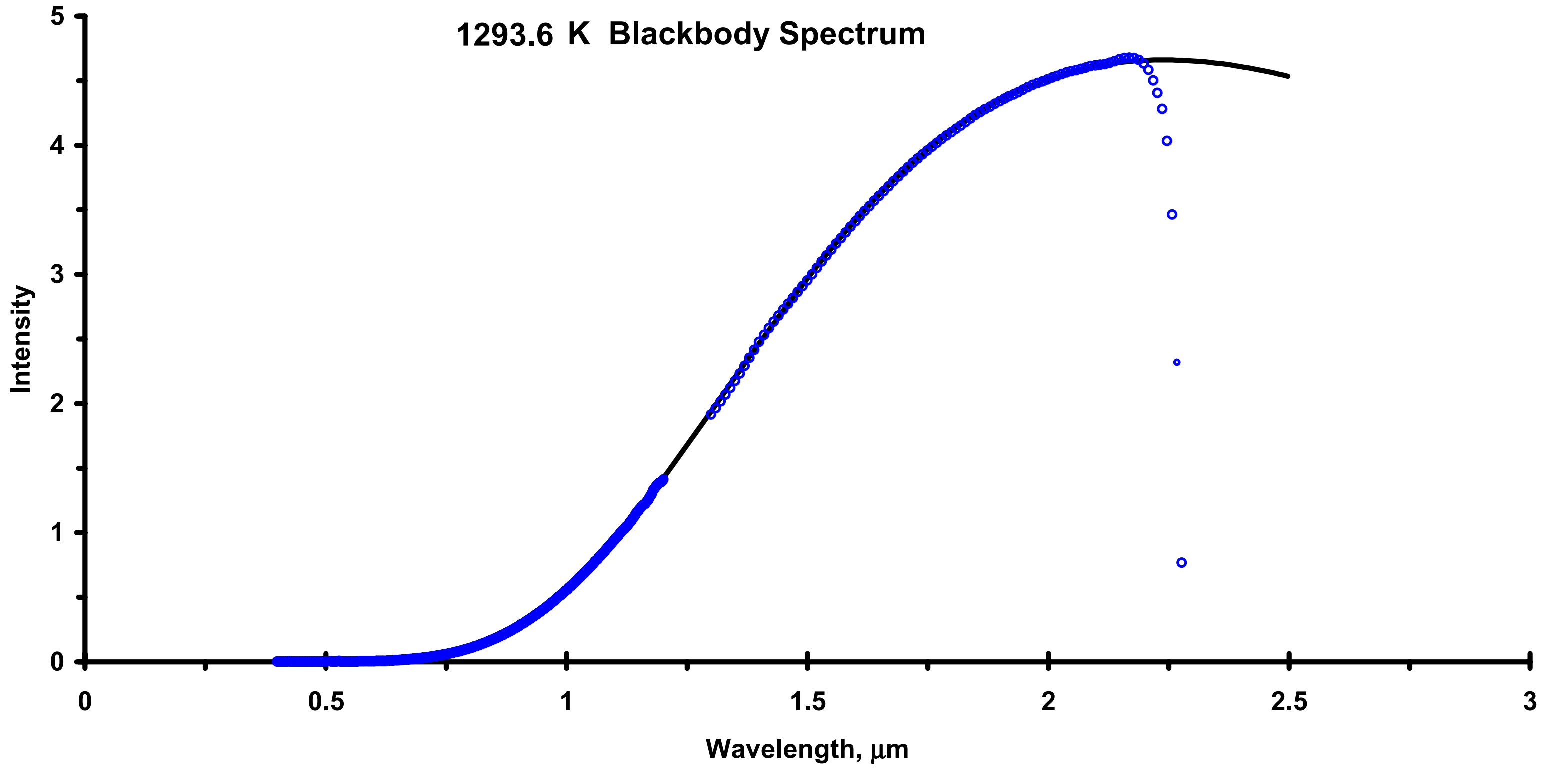

Fig. 2 Blackbody furnace spectrum. Symbols are data and solid line is the fitted line.

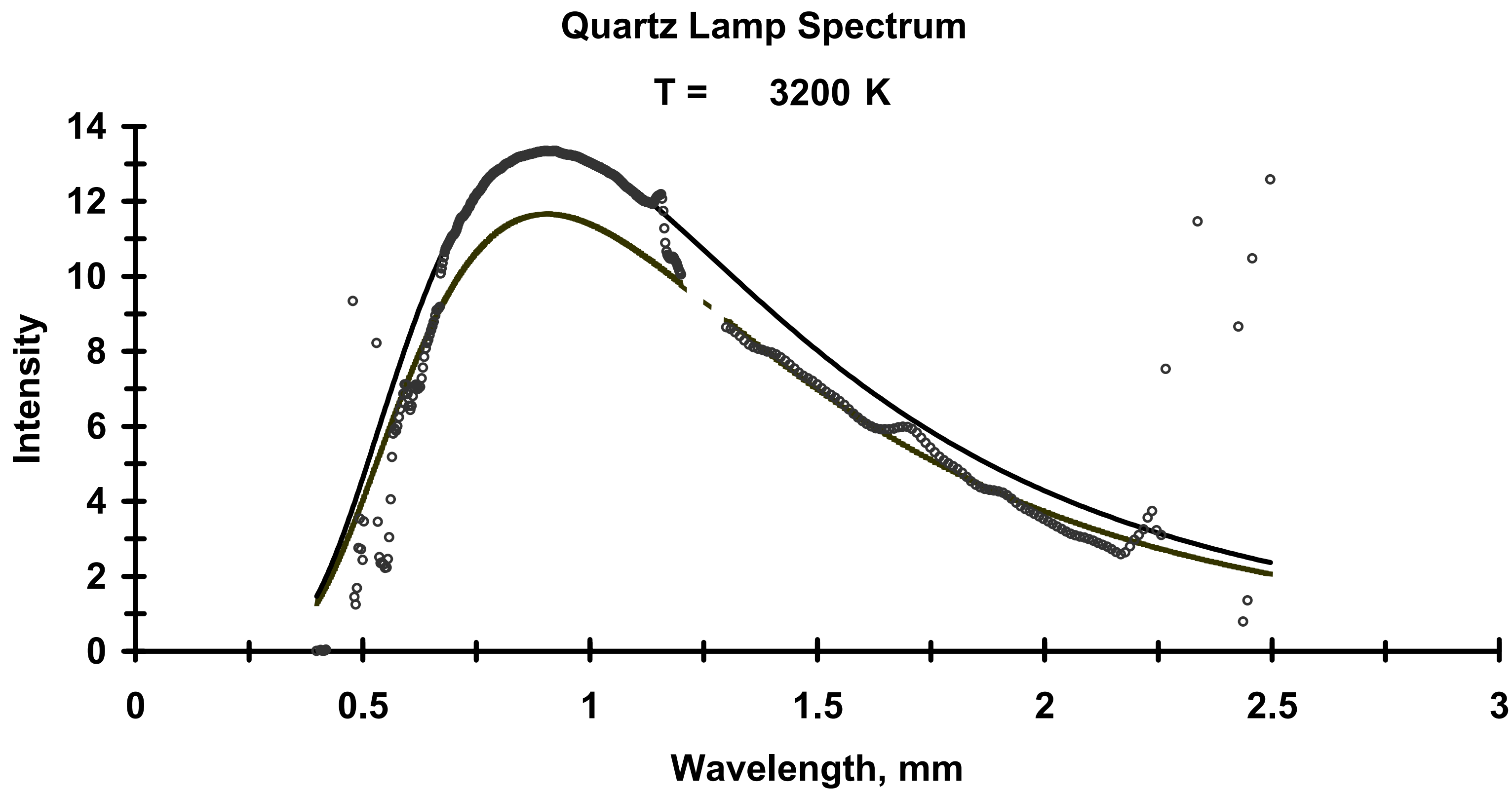

Fig 3. Quartz Lamp Radiation Spectrum

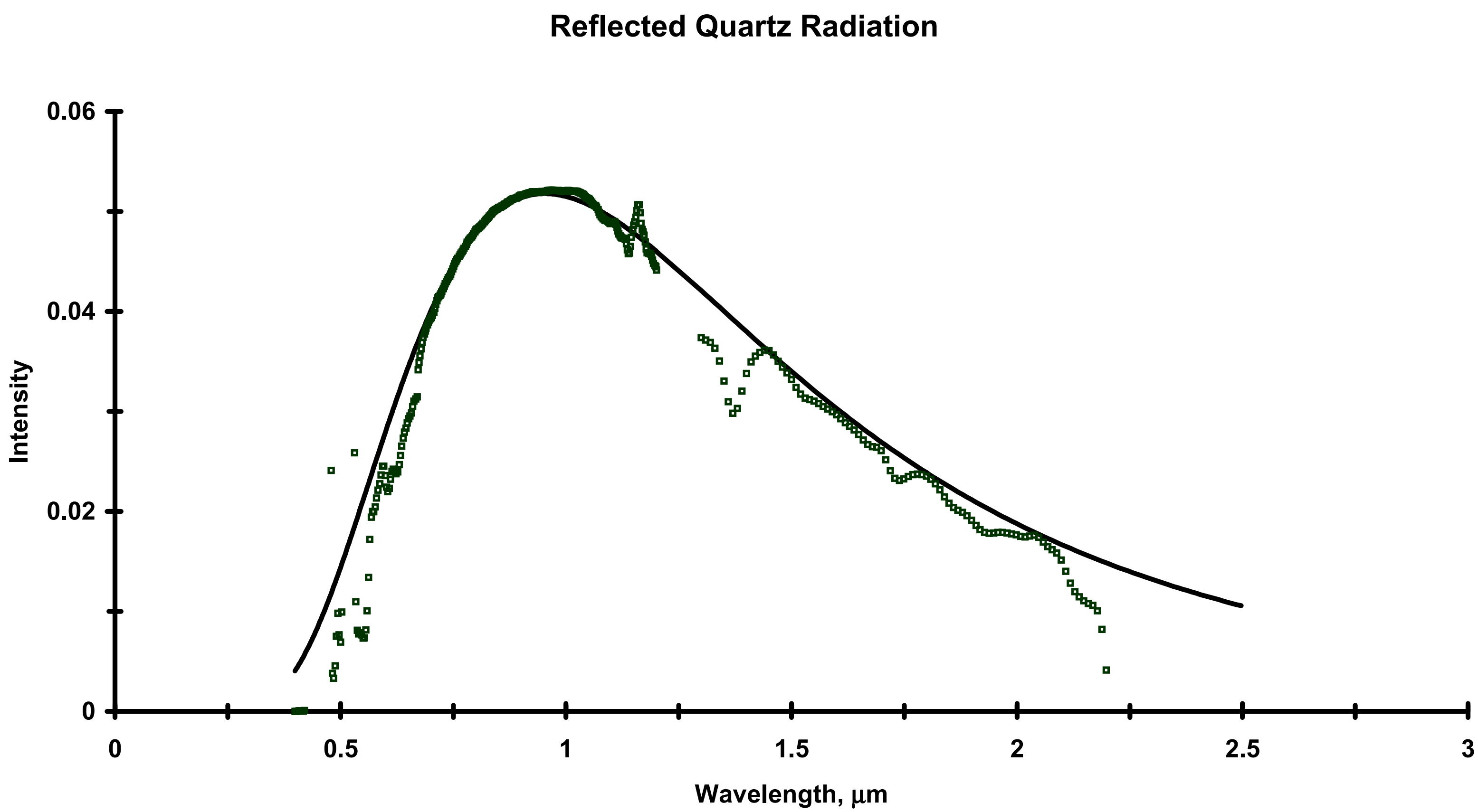

Fig. 4   Beryllia Ceramic Reflected Quartz Lamp Spectrum

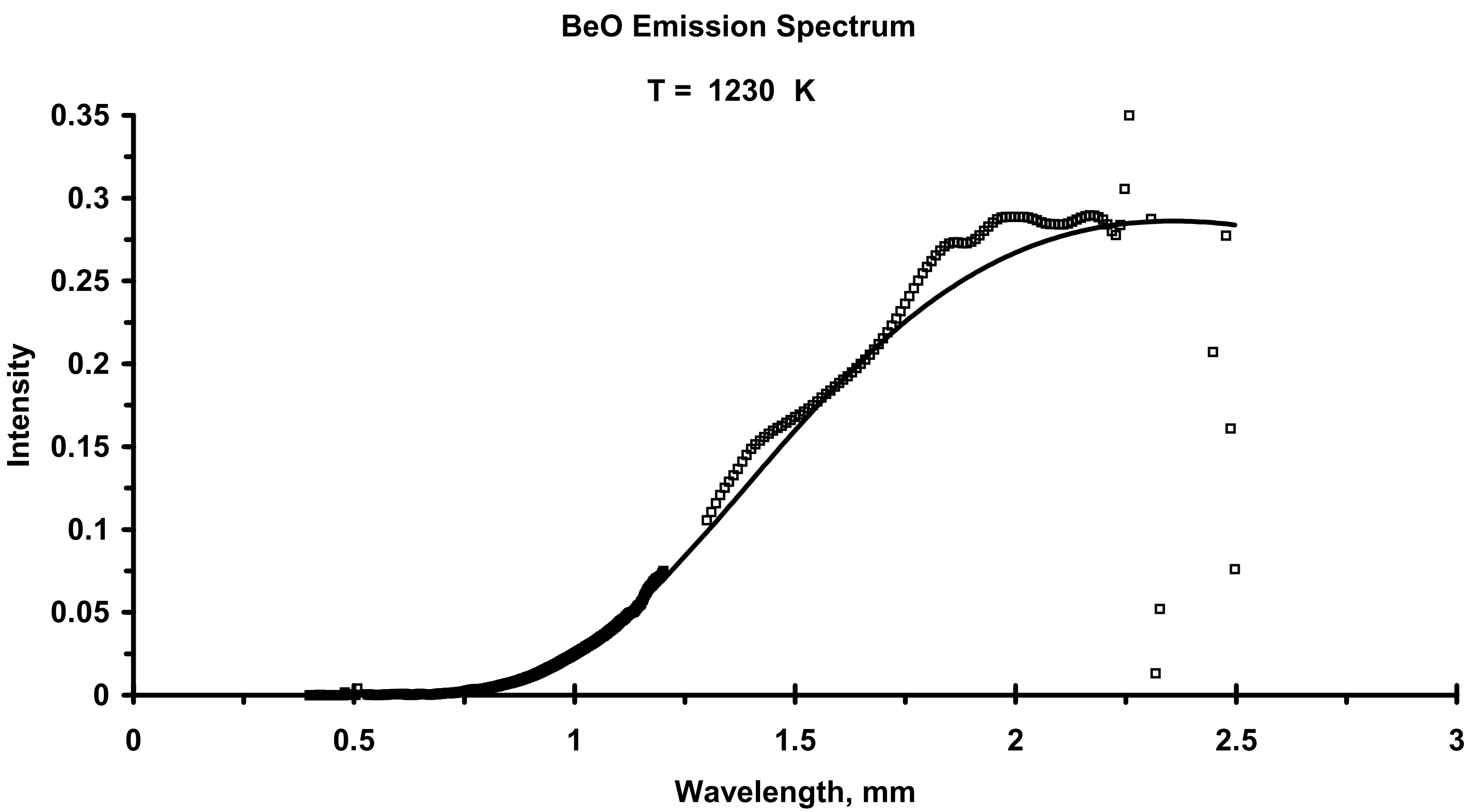

Fig. 5 Propane Torch Heated Beryllia Ceramic Surface Emission Spectrum

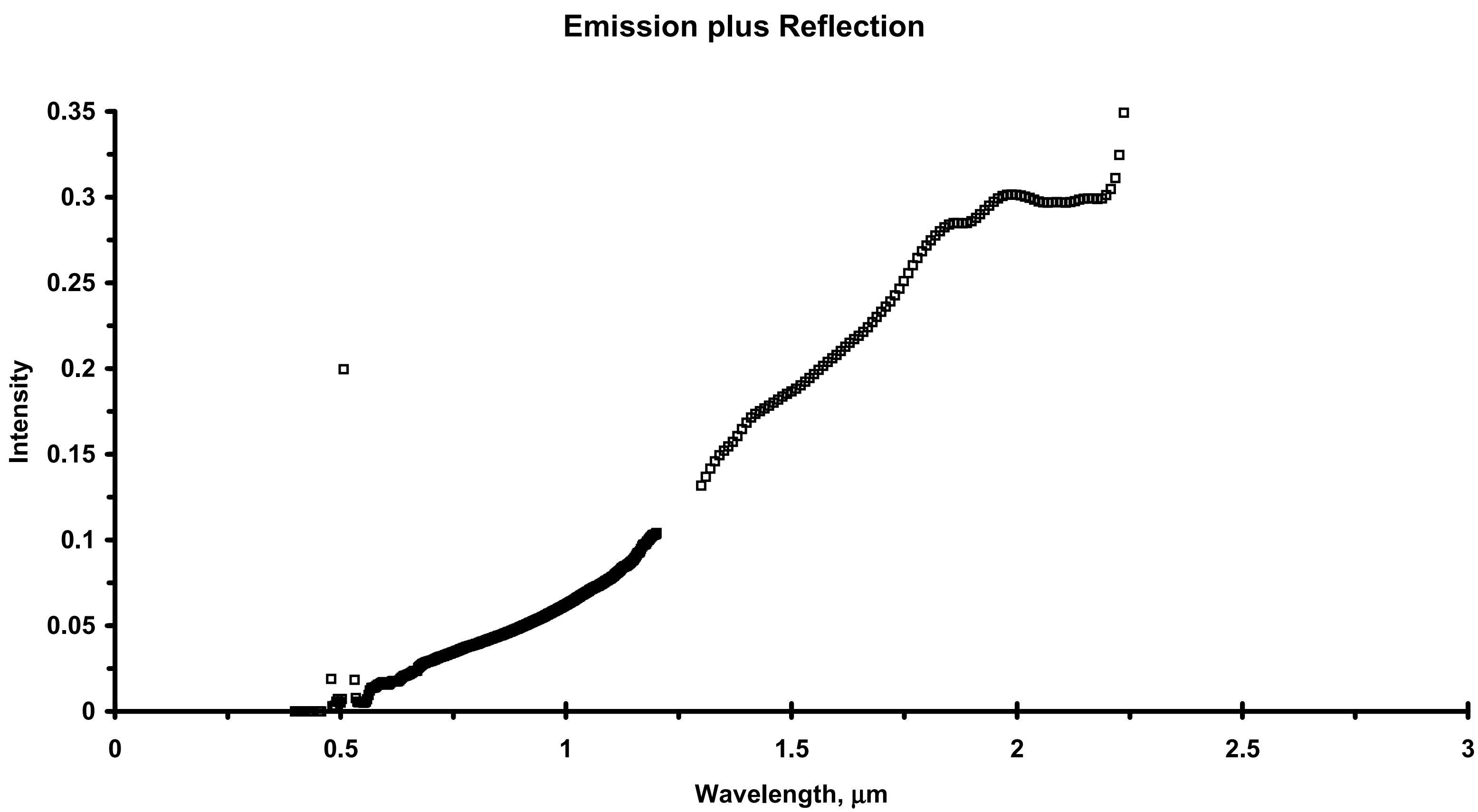

Fig. 6 Propane Torch Heated Beryllia Ceramic Surface Emission Spectrum Plus Reflected Quartz Lamp Radiation.

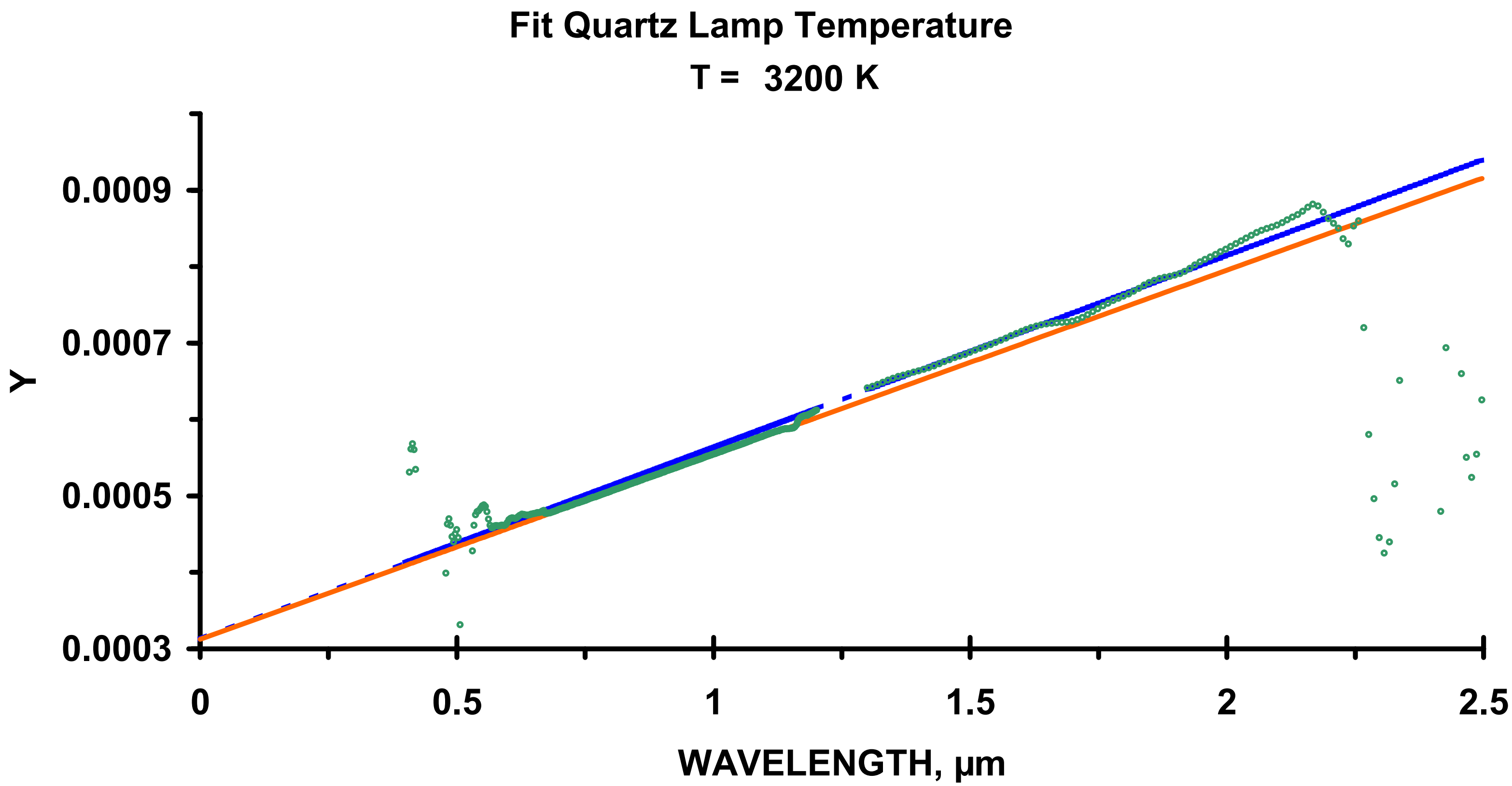

Fig. 7 Quartz lamp temperature determination from the reciprocal of the intercept.

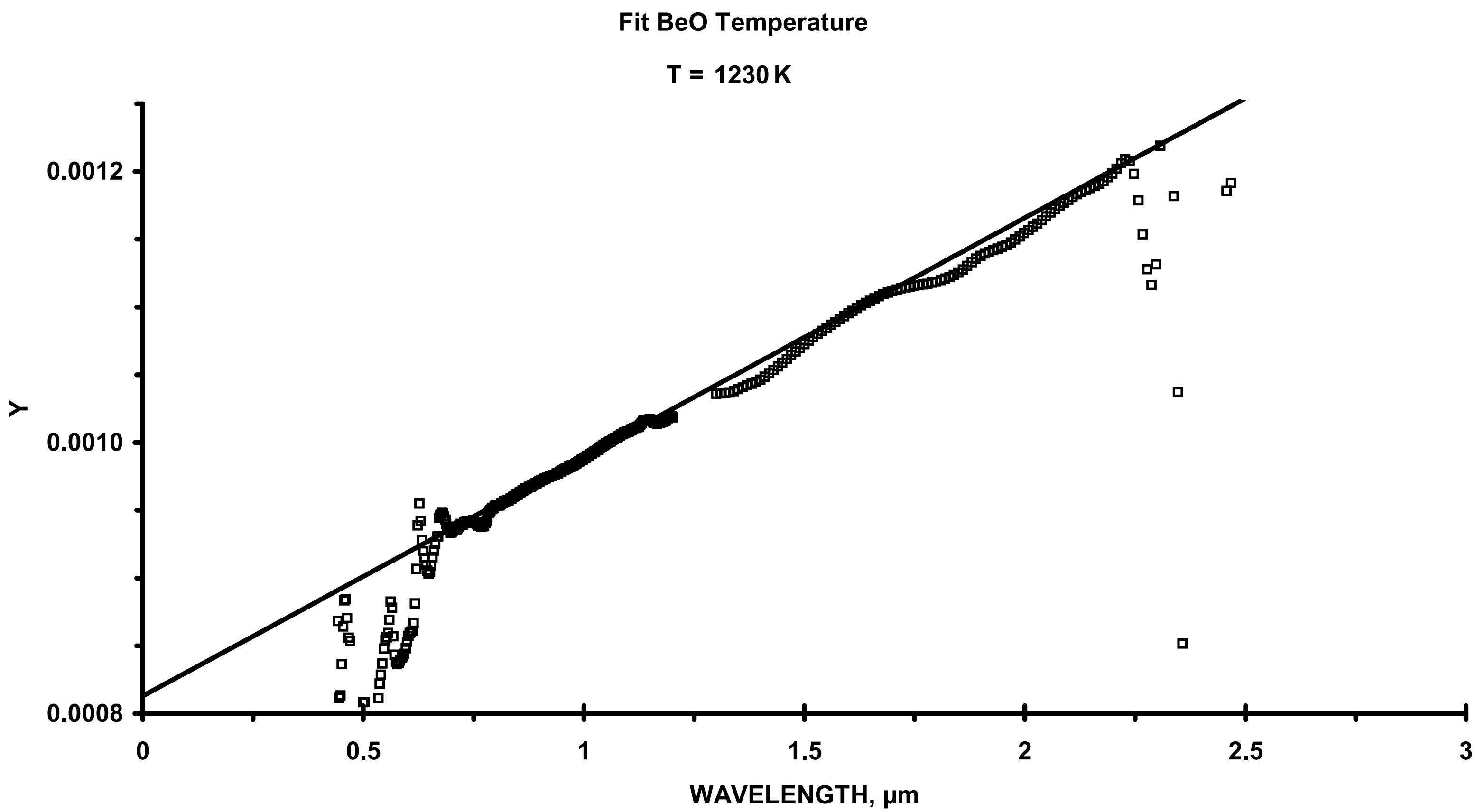

Fig. 8 BeO ceramic Temperature Determination from the Intercept.

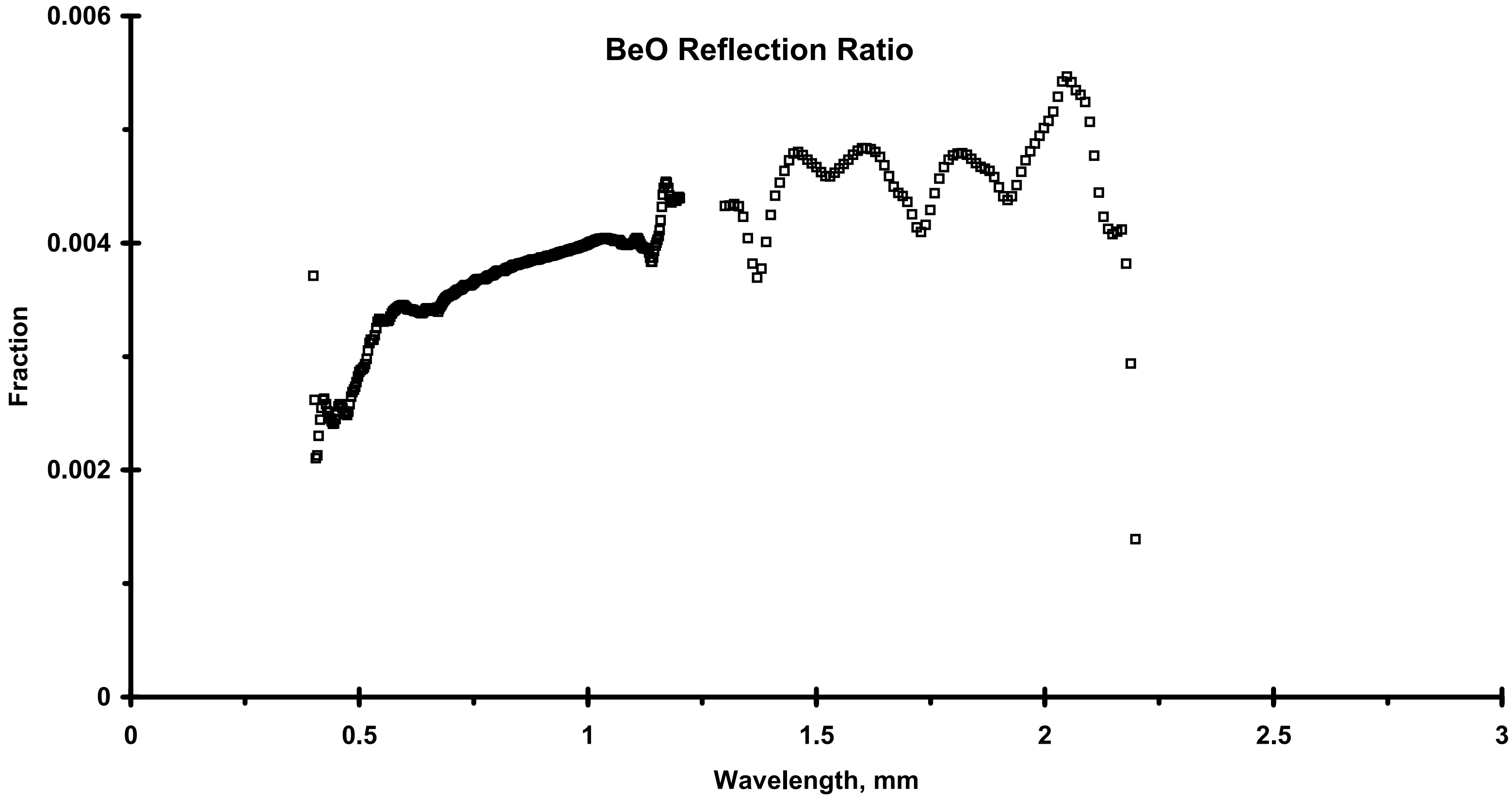

Fig. 9 Fraction of Radiation Reflected by the Beryllia Ceramic Surface.

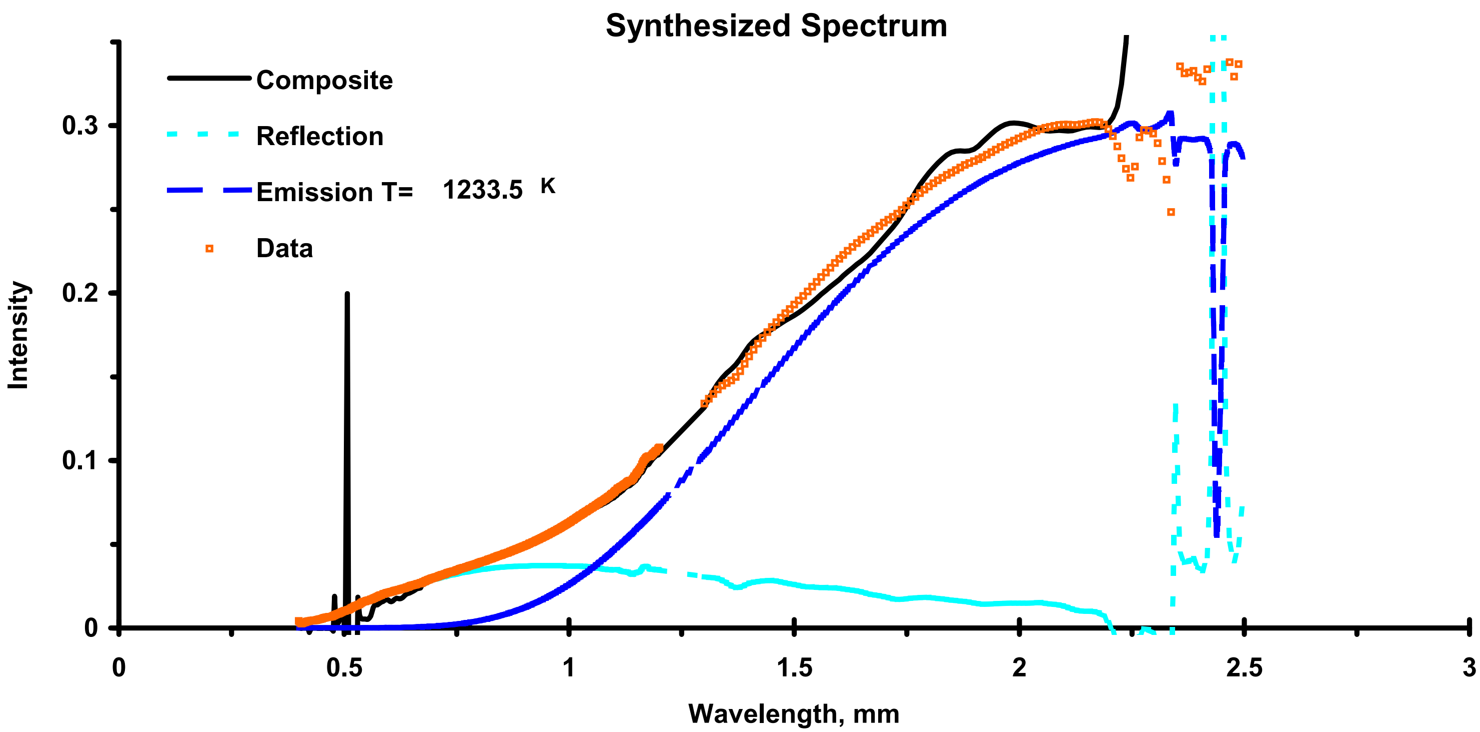

Fig. 10 Synthesis of the Spectrum in Fig. 6 from two components.

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13. ABSTRACT ***(Maximum 200 words)***

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